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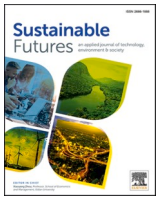

Ecological product value realization: Lessons learned from practice in China

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ABSTRACT

The 2030 Agenda for Sustainable Development, adopted at the 70th session of the United Nations General Assembly, marks the beginning of a new era for humanity to move toward a sustainable society. The ecosystem and socioeconomic system constitute a more grand and complex system with a close relationship between socioeconomic and ecological elements. The realization of the value of ecological products plays a fundamental and complex role in promoting sustainable development goals. Through a literature review and practical experience in related fields, as well as analyses of three typical cases in different geographic locations in China, we find that the reform approach of turning "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders" has broadened the opportunities to realize the value of ecological products. Specifically, the conversion of ecological value can be realized using ecological protection compensation, ecological industrialization operation, and the property rights trading of ecological resources. The realization of the value of ecological products provides a new model and practice for effectively responding to climate change, improving the quality and stability of ecosystems, promoting equity, and thus realizing sustainable development. China's experience and practices have improved the residents' well-being and financial standing while preserving ecology, and these successes provide references for countries facing development dilemmas similar to those in China.

1. Introduction

As the global population increases, the obsessive pursuit of economic growth has also brought about a surge in natural resource consumption [1], biodiversity loss [2], pollution and land degradation [3], even to the detriment of social equity and human well-being [4]. Human and other life on Earth may be approaching a catastrophic tipping point [5]. There is an urgent need to develop specially designed large-scale, innovative and policy-coherent solutions to address global societal challenges such as climate change, food and water security, natural disasters, and human health. In response to the challenge, people have moved from being passive beneficiaries of nature to actively protecting, managing or restoring ecosystems [6].

In an ecosystem, all matter, energy, information, time, and space utilized by organisms and human beings for their survival, reproduction, and development can be considered ecological resources [7]. Broadly speaking, the value of all ecological resources can be recognized as ecological assets [8]. These ecological assets form the basis of ecological products. The concept of ecological goods was first introduced in China, and its core meaning is similar to that of ecosystem services [9]. Ecosystem services refer to the conditions and processes through which natural ecosystems and the species within them maintain and support human life, highlighting the interdependence of humans and ecosystems [10]. In contrast, ecological products focus more on their transformation into economic entities within human society through human labor [11]. Therefore, ecological products encompass a variety of products and services obtained from nature or processed by humans, fulfilling roles such as material supply, life support, environmental enhancement, and cultural heritage [12]. Ecological products can be categorized based on their attributes into purely public ecological products, quasi-public ecological products, and business ecological products [13]. The overall value of ecological products comprises both the value of the material products and the functional services they provide for human survival and development [14]. Realizing the value of ecological products involves maintaining ecosystems, leveraging local ecological resource advantages, rationally developing and utilizing ecological products, and

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converting the ecological value of these products into economic benefits [15].

The ecological product value realization in China is the rational and effective monetisation of the ecological values inherent in mountains, rivers, forests, fields, lakes, grasslands, sand and ice [16]. In 2021, China issued the 'Opinions on Establishing and Improving the Value Realisation Mechanism of Ecological Products' and actively encouraged provinces and cities across the country to realize the ecological product value realization. The core idea of the policy is that those who protect the ecosystem should be compensated in some way, those who use the ecosystem should pay for it, and those who destroy the ecosystem should be fined [17,18]. In other words, by promoting ecological conservation and restoration of different types of ecosystems, thereby realising the value of ecological product.

By reviewing previous studies, we find that there are few studies analysing the benefit linkage mechanism of ecological product value realisation.These studies have mainly focused on the process and utility of ecological product value realization [19–21]. Although scholars have noticed that institutions play an important role in the marketization of ecological resources factors, however, there is no clear answer as to how to enhance the welfare of participants under the premise of ecological protection and economic growth [22]. In addition, as perceptions of the relationship between humans and nature change several issues arise: How to rearrange and combine the elements of ecological resources and realize marketization? How to integrate ecological protection, economic growth and people's welfare? A better understanding of these issues is essential for decision-making related to ecological and environmental protection in many emerging economies such as China.

Therefore, the purpose of this paper is to discuss the feasible ways to promote the conversion of the value of ecological products in China, and the significance of the institutional reform to promote the development of 'harmonious relationship between human and nature' in China. Specifically, through the ecological resources into ecological assets, owned capital into share capital, and householders into shareholders ('three changes' reform), it promotes the realization of the value of production products and connects the benefits of transformation to the well-being of the people. Firstly, this involves turning ecological resources into ecological assets. That is to say, collective land, forest land, waters, and other natural resource elements are transformed into shares and different ways to join new business entities. This approach is conducive to revitalizing ecological resources, transforming public goods with positive externalities into assets, and unifying their absolute and market values. Secondly, owned capital is turned into share capital. That is to say, without changing the nature and purpose of the use of capital, financial investments at all levels in the forms of rural agricultural production and development capital, agricultural resource and ecological protection subsidy capital, poverty alleviation, and development capital, rural infrastructure construction capital and village collective development capital are quantified as village collective share capital and invested in various types of business entities. Thirdly, householders are turned into shareholders. That is to say, householders offer their personal resources, assets, capital, technology, skills, etc., as contributions to the operating body, and in return, they become shareholders and participate in dividends. This approach is conducive to the standardization and scaling up of ecological products, thus enhancing the bargaining power and competitiveness of ecological products in the market and alleviating the contradiction between the long-term realization of ecological product value and the short-term benefits valued by individual householders.

2. Background and methods

2.1. Background

2.1.1. The policy background of the ecological products value realization

In China, the rise of the economy, environmental problems (including resource depletion [23] and ecological damage [24] have come one after another. These problems are complex in structure, wide-ranging, and have far-reaching impacts. Today, China is faced with the dual task of developing the national economy and protecting the ecological environment [25], and there is an urgent need to seek a sustainable development model that balances the two. In 2010, China introduced the concept of ecological products in the policy document entitled "National Main Functional Areas Planning," identifying the enhancement of ecological product production capacity as an essential task in the spatial development of the national territory. In August 2016, "the Implementation Plan for the National Ecological Civilization Pilot Area (Fujian)," introduced in China, proposed for the first time the idea of value realization based on the concept of ecological products. In 2021, China issued the "Opinions on Establishing and Improving the Value Realization Mechanism of Ecological Products" and began to actively encourage provinces and cities across the country to realize their ecological product value. The core idea of the policy is that those who protect the ecosystem should be compensated in some way, those who use the ecosystem should pay for it, and those who destroy the ecosystem should be fined. In other words, by promoting ecological conservation and restoration of different types of ecosystems, the value of the ecological product can be realized [26]. The concept of ecological products and their value realization has gradually deepened and sublimated with the deepening of China's ecological civilization construction (Table 1).

2.1.2. The practical background of the ecological products value realization

Ecological product value realization has become a significant national practice in China [27]. In June 2016, Fujian was designated as the country's first National Ecological Civilization Pilot Zone, marking the initial step in exploring the practical realization of ecological product value. In 2017, Guizhou Province, also a National Ecological Civilization Pilot Zone, began seeking effective pathways for ecological product value realization. That same year, the Ministry of Ecology and Environment encouraged local governments to explore best practices and experiences in transforming ecological value into economic benefits. Since 2020, the Ministry of Natural Resources has identified four batches of 43 exemplary cases of ecological product value realization, summarizing three distinct models: government-led, market-led, and "government + market" collaborative approaches. In May 2024, the National Development and Reform Commission designated 10 districts, including Beijing's Yanqing District, as the first batch of national pilots for ecological product value realization mechanisms. This initiative laid the groundwork for exploring more diverse pathways for ecological product value realization. Currently, 28 provinces in China have issued implementation guidelines or plans to establish and improve mechanisms for realizing the value of ecological products. Many provinces, such as Shandong, Hubei, Fujian, Sichuan, and Guangxi, have launched provincial-level pilot projects. By examining the practical background of ecological product value realization, it is evident that this process has become a crucial component of deepening China's ecological civilization system reform. It is also one of the most important strategies for promoting sustainable development in China.

2.2. Methods

A holistic research method was used in this study. The popularity of holistic research as a qualitative method is increasing every year. When employing the holistic research method, we can gather more comprehensive information by providing detailed descriptions of events. This approach allows us to gain a deeper understanding of the context and experiences related to the case. It is particularly well-suited for in-depth analysis of a limited number of social phenomena through direct observation [28]. Furthermore, this method not only addresses broader and more complex questions but also enables the use of texts, images, and dialogues to present unique perspectives.

Table 1
Evolution of ecological product value realization.

Times	Significant Documents or Events	Meaningful Interpretation
December 2010	National Main Functional Areas Plan	The concept of ecological products was first introduced in a Chinese government document.
November 2012	The 18th National Congress of the Communist Party of China (CPC)	Increase efforts to protect natural ecosystems and the environment and enhance the production capacity of ecological products.
November 2013	Decision of the Central Committee of the Communist Party of China on Several Major Issues Concerning Comprehensively Deepening Reforms	Putting forward the concept of "mountains, water, forests, fields and lakes" as a community of life.
May 2015	Opinions on Accelerating the Construction of Ecological Civilization	Deepening price reforms for natural resources and their products
September 2015	General Programme for the Reform of the Ecological Civilization System	Natural ecology is valuable.
August 2016	The Implementation Plan for the National Ecological Civilization Pilot Area (Fujian)	First concept of value realization of ecological products.
October 2017	The 19th National Congress of the Communist Party of China (CPC)	Provides more high-quality ecological products to meet people's growing needs for a beautiful ecological environment.
December 2018	Action Plan for the Establishment of a Market-based and Diversified Compensation Mechanism for Ecological Protection	Realizing the value of ecological products with market-oriented and diversified ecological compensation methods.
April 2020	Master Plan for Major Projects for the Protection and Restoration of Nationally Important Ecosystems (2021–2035)	Enhancing the productive capacity of ecological products as a goal of ecological restoration.
April 2021	Opinions on Establishing and Improving the Value Realization Mechanism of Ecological Products	Important strategic deployment for the realization of the value of ecological products.
October 2022	The 20th National Congress of the Communist Party of China (CPC)	Establishing mechanisms for realizing the value of ecological products and improving the compensation system for ecological protection.
December 2023	The central financial work conference	Improves the mechanism for realizing the value of ecological products

The primary objective of this study is to explore how the reform approach of "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders" can facilitate the realization of ecological product value. However, due to the variability and complexity of ecological product value realization in terms of technology and mechanisms, its implementation process and outcomes have not yet been systematically studied. Therefore, we employed a holistic research method to analyze three representative cases in China. On the one hand, this method allows us to map out a general pattern by detailing each step of the research process, thereby enhancing the feasibility and rigor of the research process. On the other hand, we can use this method to compare different cases both horizontally and vertically, leading to more realistic conclusions and thereby improving the scientific accuracy of the research results. In summary, the application of the holistic research method provides a new way of thinking to promote the realization of ecological product value.

Step 1. Define research questions. The following three questions were formulated for this study: (1) What model has China adopted to promote the realization of ecological product value? (2) How does the reform of turning "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders" empower the realization of ecological product value? (3) Are the instruments used to date effective in advancing the realization of ecological product value?

Step 2. Select cases to be studied. To answer the above questions, we chose the case study method because it is suitable for the in-depth study of socio-economic phenomena with few observations. Many regions in China face a contradiction between ecological protection and economic development. Some areas have rich ecological resources but lack the knowledge or means to utilize them effectively, leading to slower economic development. Conversely, other regions prioritize economic growth at the expense of environmental health, resulting in a rapid decline in ecological well-being and creating a vicious cycle.

The Notice on Typical Cases of Realizing the Value of Ecological Products (first batch), issued by the Ministry of Natural Resources of the People's Republic of China covers typical results achieved in various regions in actively exploring the realization of the value of ecological products. The Department of Natural Resources of the Guangxi Zhuang Autonomous Region issued the Typical Cases of Realizing the Value of Ecological products in the Guangxi Zhuang Autonomous Region, which is targeted at practicing the path of transforming the value of ecological products. On this basis, based on China's criteria for the division of east, central and west, and also using the final level of economic development and the degree of ecological protection as indicators, three regions, Guangxi, Hubei and Fujian (Fig. 1), were selected to categorize and expound on the three reform modes of resource-to-asset, capital-to-stock, and forest-farmer-to-stock-farmer, which are covered by the process of realizing the value of ecological products.

Step 3. Data sources and analysis. The data for this study are derived from three primary sources. The first source includes the "Notice on Typical Cases of Realizing the Value of Ecological Products (First Batch)" and the "Typical Cases of Realizing the Value of Ecological Products in the Guangxi Zhuang Autonomous Region," which serve as our foundational data. The second source consists of information obtained from government websites and enterprise webpages. The government data provides insights into the local economic and social conditions, as well as the support measures implemented to guide the "three changes" reform. The enterprise data focuses on the industrial structure, development, and strategic direction. The third source is based on the team's field interviews, through which we have in-depth exchanges with government departments, enterprises and farmers on the specific ways of realizing the value of ecological products, the application of ecological value, economic value and social value, the challenges in the process of realizing them, and the ways of solving the problems, etc., so as to help us grasp the research process more precisely and identify typical patterns.

Step 4. Summary and review. Firstly, we surmised that the reform method of turning "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders" effectively promotes the realization of ecological product value.We analyzed and compared the effectiveness of the three models. Secondly, we analyzed the programs implemented in other countries and regions of the world to advance the value realization of ecological products, and we compared those with the Chinese programs included in this study. Finally, we analyzed this study's limitations and outlined the most substantial avenues for further optimization in realizing ecological product value.

The steps of this study are shown below (Fig. 2).

Fig. 1. Research region.

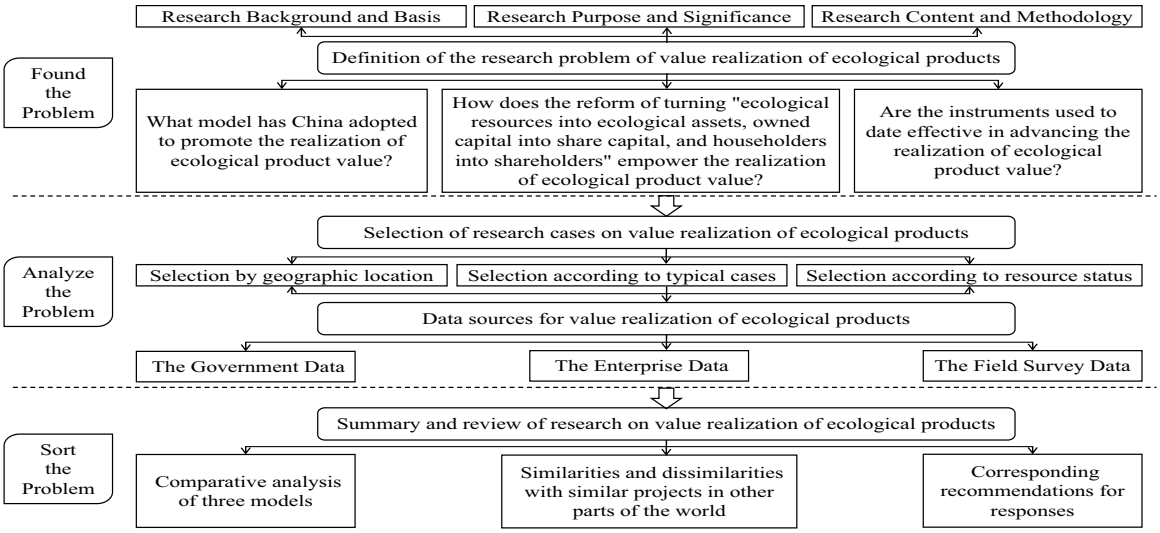

Fig. 2. Research technology roadmap.

3. Theoretical logic of ecological product value realization

The realization of the value of ecological products plays a vital role in synergizing economic growth and environmental protection. The value of ecological products is based on the premise of protecting and improving the ecological environment so that a good ecological environment, like labor, capital, technology, and other factors of production, becomes a core factor of production for sustainable development. This part fully considers the intrinsic relationship between ecological, environmental protection, and high-quality development and analyzes the ecological, economic, and social logic of realizing the value of ecological products from the theoretical level.

3.1. Ecological logic of value realization of ecological products

Good ecological resources are not only ecological factors but also factors of production [29]. Ecosystems contain many ecological resources, most of which can be transformed into ecological assets and enter the process of production and reproduction in human society. The protection and restoration of ecosystems and the continuous improvement of ecosystem diversity and stability will help to improve the sustainability of the supply of ecological products. Many developing countries are endowed with a good ecological environment and abundant ecological products [30]. However, economic development is lagging behind due to the lack of capacity and ways to transform ecological resources into ecological assets in these areas. Therefore, how to give full play to ecological advantages, promote the transformation of

ecological advantages into industrial and economic benefits, and enhance the sustainable supply capacity of high-quality ecological products has become a hot issue in promoting coordinated development.

The ecological logic of realizing the value of ecological products is reflected in the following two aspects: first, a good ecological environment is the fundamental guarantee of ecological products. A sound ecological environment is also a source of potential and competitiveness for achieving the goal of sustainable development. Secondly, a good ecological environment makes producing and supplying ecological products possible. Ecological product value realization makes natural resources no longer a single ecological element. A single natural resource can only provide spiritual support for the residents to a certain extent. Still, it cannot bring them a genuinely affluent life, making it challenging to realize sustainable development. Therefore, it is significant to open up channels for transforming ecological resources into ecological assets.

3.2. Economic logic of value realization of ecological products

The realization of the value of ecological products is a complex systematic project [31]. The value of ecological products is enormous, but not all ecological value can be converted into economic value [32]. Therefore, it is significant to systematically analyze the value of ecological products and identify the parts that can be converted into economic value. In recent years, the value of ecological products has gradually been highlighted and recognized in the market. It means that ecological products improve the utility level of consumers, and people are willing to pay the corresponding price for the benefits brought by ecological products. Therefore, an effective market plays a significant role in advancing the economic value of ecological products [33].

The economic logic of realizing the value of ecological products is embodied in the following three aspects: first, carrying out ecological product value assessment. Ecological product value assessment is a prerequisite for realizing the transformation of ecological products from ecological value to economic mechanism. Secondly, the transformation path of ecological products should be clarified. In recognizing the value of ecological products, it is necessary to scientifically identify the attributes of ecological products and the part of ecological product value that can be transformed into economic value and clarify its transformation path. Third, promote the innovation of ecological product value realization mechanisms. Economic development cannot be separated from the role of the market. Therefore, the market trading platform for realizing the value of ecological products is critical so that the government, enterprises, residents, and multiple other subjects can benefit from it.

3.3. Social logic of value realization of ecological products

The formation of ecological products has both the role of natural factors and the role of human social activities [34]. The realization of ecological product value is based on ecological protection, the protection and restoration of the ecological environment through labor input, so that ecological resources or other ecological products are transformed into the intrinsic value of human labor. For producers, ecological product value recognition will stimulate them to improve the supply capacity of ecological products [35]. Pursuing green and healthy lifestyles will consumers' demand for ecological products [36]. The realization of the value of ecological products protects and restores the ecological environment, creates employment opportunities for residents, and promotes economic development.

The social logic of realizing the value of ecological products is reflected in the following two aspects: first, realizing the value of ecological products requires the dual promotion of the government and the market. The realization of ecological product value needs to play a full role in the decisive role of the market in resource allocation and the macro-control role of the government. At the same time, the realization of the value of ecological products needs to be jointly promoted by the government, enterprises, residents, and other multi-dimensional subjects. Secondly, the realization of ecological product value should focus on fair distribution. Production determines distribution. The distribution mechanism plays a vital role in socially redistributing ecological products. The fairness of distribution can promote the sustainable operation of the ecological product value realization mechanism and reduce inequality within or between countries.

3.4. Concrete embodiment of the "three changes reform" in the theoretical logic of ecological product value realization

In the theoretical framework of realizing the value of ecological products, the essence of reform is to crack the contradiction between ecological protection and economic development through institutional innovation and system synergy, and to realize the in-depth coupling of ecological logic, economic logic and social logic. It is to transform the integrity constraints of the ecosystem into the value-added power of the economic system, and then to feed the ecological sustainability with the fairness guarantee of the social system, so as to ultimately realize the coordinated development of human beings and nature, efficiency and fairness, growth and well-being.

Ecological resources into ecological assets is based on ecological logic. This process involves defining property rights for natural resources and implementing ecological value accounting. Elements such as mountains, water, forests, and fields will be converted into quantifiable and tradable assets. This transformation not only enhances the rigidity of ecological protection through property rights constraints but also activates the economic value of these resources through market-oriented configurations. Simultaneously, it safeguards the rights and interests of indigenous people, ensuring their status as primary stakeholders of these resources is clearly recognized.

Owned capital into share capital is based on economic logic. We can promote the injection of financial resources and social capital into ecological protection and the green industry in the form of equity. This approach not only expands the scale of ecological investments through the capital appreciation cycle but also uses the returns on equity to fund ecological restoration efforts. Furthermore, mechanisms such as collective shares and public welfare shares are designed to ensure that the capital gains benefit the main stakeholders involved in protection, particularly disadvantaged groups.

Householders into shareholders is based on social logic. By converting land management rights, ecological labor, and other elements into shares, householders are shifted from being mere resource users to active market participants. This transformation not only expands avenues for farmers to increase their income but also incentivizes their active involvement in ecological protection. Furthermore, it can reshape social fairness by transforming identities and facilitating a paradigm shift in ecological dividends from a model of "minority possession" to one of "multiple sharing".

4. Results

4.1. Turning ecological resources into ecological assets: ecological protection compensation

Ecological products under the ecological protection compensation model are purely public ecological products, so the government generally promotes the realization of the value of ecological products. The ecological protection compensation model involves the three dimensions of regional natural ecological surveys, establishing an ecological protection compensation system, and applying ecological values. The property rights of natural resources are defined by constructing a natural resource accounting and evaluation system. Natural resources with clear property rights, such as land, forests, water, biological, and mineral resources, can be used to develop specific ecological

protection compensation strategies based on their development potential. For natural resources with unclear property rights, such as water conservation zones, the ecological value of natural resources can be explored and transformed into assets. Ecological protection compensation includes both horizontal and vertical ecological compensation [37]. The government, financial institutions, and owners or operators of ecological assets jointly promote the application of ecological value.

Ezhou City is located east of Hubei Province and on the south bank of the middle reaches of the Yangtze River, with good natural resource endowment. However, in the past, Ezhou City only focused on economic development and neglected the protection of the ecological environment, creating a contradiction between the two that is increasingly apparent. To change this situation and promote green and sustainable development, efforts have been made to explore and form a plan for introducing a mechanism that upholds the importance of ecology in Ezhou City, and accordingly, a green channel has been opened up from resources to assets [38]. In tandem with this, efforts have begun to explore a practical development pathway led by the government, followed by enterprises and all sectors of society, and operated by the market [39].

First, a natural resource accounting and evaluation system has been established to facilitate the assetization of ecological resources. Through surveys of natural resources and the registration of rights, Ezhou City has quantitatively assessed key indicators such as ownership, boundaries, area, quantity, and quality of natural resources. This work lays a solid data foundation for preparing the natural resources balance sheet. The Equivalent Factor Method, applicable at both regional and global scales, has been selected to calculate and assign values to ecological resources. Based on the abundance of vegetation, water quality and precipitation in each district, the total monetary value covering the five key ecological areas of water flow, forests, wetlands, arable land, and atmosphere is calculated by zones. Cross-regional ecological compensation is then determined according to the value of ecological services provided by each district. According to the measured data from 2017 to 2020, the Liangzi Lake District of Ezhou City received ecological compensation transfer payments of $7 million, $11.48 million, $12.76 million, and $14.35 million, respectively (Fig. 3).

Secondly, to turn ecological resources into ecological assets, a compensation mechanism for ecological protection should be established to achieve the marketization of ecological assets. In promoting the marketization of ecological assets, by the principle of "who pollutes, who compensates, who protects, who benefits," Ezhou City has taken the financial transfer payment as a carrier in establishing an ecological value compensation mechanism between different administrative divisions. In making compensation for ecological protection, considering the financial ability of districts to pay, the compensation for ecological protection is initially weighted at 20 percent of the total value of the ecological services provided, of which the municipal government subsidizes 70 percent. The remaining 30 percent is transferred by the district that receives the ecological services. The proportion of weighting is then increased year by year to reduce the proportion of subsidies from the municipal government gradually.

Finally, the mode of realizing ecological product value and financializing ecological assets should be innovated to turn ecological resources into ecological assets. The government requires actively guiding various banking and financial institutions to continuously expand loan varieties and scales, thereby gradually realizing the full coverage of ecological asset pledge financing varieties. Efforts are also required in guiding owners or operators of ecological assets, such as forest rights, mineral rights, and sewage rights, to use their holdings of future income rights as the subject matter of financing and to list and transfer their income rights through rural property rights trading venues, to achieve the financialization of ecological assets. Beyond such efforts, Ezhou City has also docked with national policy financial institutions, strengthening the ecological environment's management and promoting the organic combination of ecological protection and economic development.

This study concludes that Ezhou City, based on the actual situation, adheres to government-led development, revitalizes natural resources, and uniformly measures all kinds of services and contributions provided by the natural ecosystems, prompting local resources to be turned into assets in a way that effectively mitigates the contradiction between the ecology and the economy, and promotes the formation of a practical development situation in which human beings and nature coexist harmoniously. In this model, Ezhou City provides a satisfactory reference for feasible methods to realize ecological product value by unifying monetary units of ecological accounting, establishing and improving an ecological value accounting and ecological compensation mechanism, and turning intangible ecological resources into tangible assets (Fig. 4).

4.2. Turning owned capital into share capital: ecological industrialization operation

The ecological industrialization operation model mainly relies on natural resources such as agriculture, forestry, animal husbandry, and fisheries to promote realizing the value of ecological products. The ecological products under this mode are mainly operational ecological products, so the auxiliary function of the market is needed. Ecological industrialization operation primarily includes three dimensions: quality improvement and efficiency of the primary industry, deep processing of the secondary industry, and integrated development of the tertiary industry. After identifying the characteristic resources, village collectives utilize collective assets and collective sites to develop ecological products. By improving the quality of the primary industry, the prosperity of the secondary industry is realized by continuously extending the

(a) (b)

Fig. 3. The case of ecological protection compensation in Ezhou City, China. (a)Mengjia River into Liangzi Lake before ecological restoration; (b) Mengjia River into Liangzi Lake after ecological restoration (https://hbj.wuhan.gov.cn/hjxw/202302/t20230223_2157777.html).

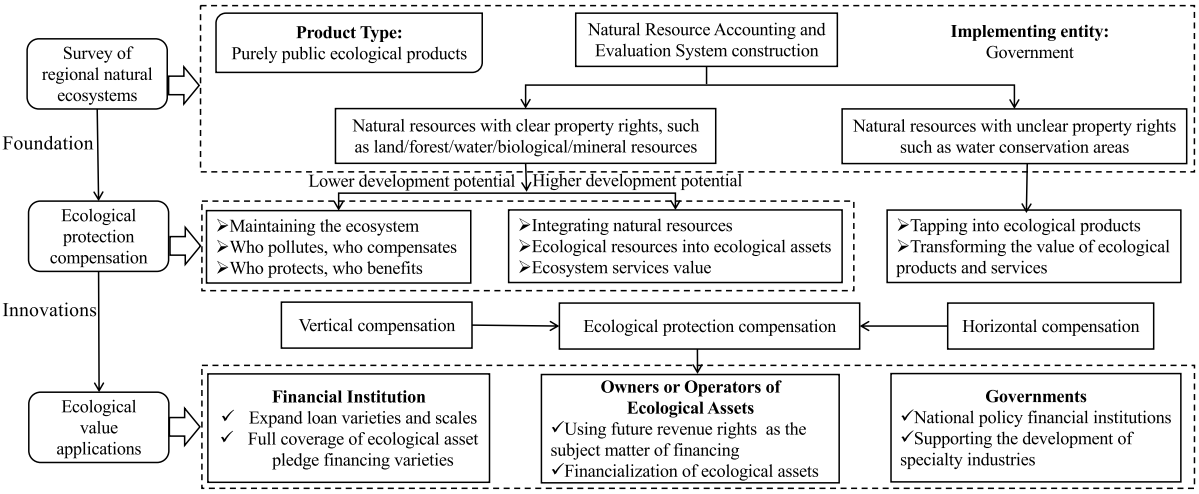

Fig. 4. Theoretical logic diagram of turning ecological resources into ecological assets.

industrial chain and creating deep processing parks. Focusing on developing the ecological tourism industry to recognize the integrated development of primary, secondary, and tertiary industries. By adopting the mode of turning funds into shares and quantifying all financial funds into village collective shares, the path of realizing the value of ecological products has been broadened.

Mengshan County is located in the northwestern part of Wuzhou City, Guangxi Zhuang Autonomous Region, with a forest coverage rate of 82.87 percent. Mengshan County is rich in plant nectar sources. However, in the past, Mengshan County has faced problems of weak brand awareness and low added value of products in the bee industry. To promote the high-quality development of the bee industry, Mengshan County has made full use of the local ecological resource advantages and explored opportunities to realize the value of ecological products in line with local characteristics [40].

Based on the actual situation, Mengshan County is looking to determine the ecological value and economic value of the fit and constantly expanding its production scale in the bee industry to create a unique brand and thereby enhance the value of its ecological products (Fig. 5a).

Firstly, the village collective share capital can then be invested in the collective construction of the village. Mengshan County has done so by adopting a variety of methods and investing more than $20.78 million in unique capital to attract farmers to participate and import technology, where farmers can receive a subsidy of $41.55 for each swarm of bees, with a maximum subsidy of $692.50 per household. Mengshan County first realized a balance between short-term benefits for farmers and ecological protection through direct economic subsidies. After the short-term benefit balancing mechanism has operated solidly, an innovative mechanism will be constructed. Specific approach is to promote 28 villagers have been charged with investing the 58 hm2 of ecologically protected forests of honey plants in the Mengshan County Fengyuan Farm. The villagers are raising >5000 swarms of bees through the mode of "ordering purchase + dividends," establishing honey processing production lines by using the collective assets and venues quantifying the capital invested in the collective economy in terms of share capital, and issuing equity certificates. Additionally, Mengshan County is opening up a green channel for beekeepers to apply for beekeeping certificates and guaranteeing the smooth flow of honey harvesting across geographical areas.

Secondly, training should be strengthened to encourage villagers to participate in ecological industrialization operation. Establishment of a scientific and technological service support team with Guangxi Beekeeping Station and other enterprises and institutions as the main body, and county, township, and village three-level linkage to carry out technical guidance and training services for honeybee farmers. On average, three training courses on bee industry work are held annually six to eight field studies and training activities are carried out, >500 individuals are trained, and support for beekeeping talents, facilities, and equipment is increased. It has also launched the implementation of

Fig. 5. The case of ecological industrialization operation in Mengshan County, Guangxi Zhuang Autonomous Region, China. Mengshan County Honey Bee Breeding Demonstration Apiary (http://www.gxms.gov.cn/mszx/zwdt/bmdt/t11816814.shtml); (b) Beekeepers checking honey production (http://zrzyj.wuzhou.gov.cn/gzdt/xydt/t17154677.shtml).

standardized management, relying on "e-commerce + entrepreneurship," "e-commerce + agricultural products," and other modes to create a combined online and offline sales model to help upgrade and transform the industry (Fig. 5b).

Finally, to turn owned capital into share capital, it is necessary to tap the potential of deep processing, continuously extend the industrial chain, and solidly promote ecological industrialization. On the one hand, in Mengshan County, efforts have been made to encourage deep processing of the bee industry by establishing a deep-processing park. On the other hand, in Mengshan County, efforts have been made to extend the bee chain. Focusing on the development of ecological recreation and tourism, Mengshan County has built a modern bee science and technology museum, integrating bee product production, popular science, sales, and tourism, and this has received 12,000 tourist visitors since 2022, significantly enhancing the development space and development value of the bee industry. Furthermore, by continuously improving its industrial layout, Mengshan County has constructed a complete bee industry chain integrating breeding, processing, production, research and development, sales, and ecotourism.

Our research found that Mengshan County has adopted the "owned capital into share capital" model, quantifying various forms of financial capital into village collective share capital and expanding the opportunities for realizing ecological product value by boosting ecological industrialization operations. Specifically, through the development of forest beekeeping, Mengshan County has realized the economical and intensive use of land resources and improved the utilization rate of forest land resources. To that end, Mengshan County has improvements to the output rate per unit of forest land and stimulation of farmers' enthusiasm to protect the forest and afforestation, protect the ecological environment at the same time, promote the rapid development of forestry, achieve short-term harvest profit, harvest the forest in the long term and support a virtuous cycle through forest and bee coordination (Fig. 6).

4.3. Turning householders into shareholders: property rights trading of ecological resource indicators

The property rights trading of ecological resource indicators model mainly relies on natural resources such as forests, which are widely distributed and have public attributes, to realize the value of ecological products. The types of ecological products under this model are quasi-public ecological products and operational ecological products. The property rights trading of ecological resource indicators model mainly involves three dimensions: comprehensive utilization of natural resources, turning householders into shareholders, and scaling up the business. The model utilizes the advantages of capital, technology, and management. It realizes the large-scale, intensive, and specialized operation of ecological products through single or combined forms such as forest proper redemption, forest land leasing, and forest trusteeship. Farmers put their personal resources, assets, capital, technology, skills, etc., into the management main body to realize joint-stock cooperative operation. This model aims to operate scattered forest resources on a large scale and realize synergistic social, economic, and ecological development.

Located in the northern part of Fujian Province, Nanping City has >78 percent forest coverage and one-third of Fujian Province's forest stock. However, before 2018, >76 % of the natural resource advantages in Nanping City were fragmented and decentralized, and problems such as difficulties in aggregating forest resources, realizing resource assets, and introducing socialized capital were prominent. To effectively crack the value of ecological resources and thus overcome those problems, Nanping City, through the "forest ecological bank" mechanism (Fig. 7a), has successfully undertaken an approach to transform its ecological resource advantages into economic development advantages by harnessing the ecological value of ecological products.

To integrate its rich natural resources and thus ensure that its sleeping ecological resources are effectively revitalized, Nanping City carried out a "forest ecological bank" pilot. This required it to draw on the commercial banks' "decentralized input, holistic output" model for centralized storage, integration, and optimization of the locally fragmented resources, and build an "ecological bank" for natural resource management, development, and operation. The running of that "bank" then necessitated the implementation of shareholding cooperation and management [41]. Firstly, a platform for the development, utilization, and management of resources should be established. In the 'forest ecological bank" and forest farmers to build a platform between the establishment of village-level forest resources operating platform. This platform will operate on the principle of voluntary participation, allowing individual forest farmers to deposit their dispersed natural resources into the operating system. These resources will then be integrated and packaged into a centralized and continuous resource pool. To address the bottleneck of social capital in rural areas, the "forest ecological bank," supported by government credit endorsement, will utilize these stored assets as a credit pool. This approach will enable financial institutions to share benefits and distribute risks effectively. In Nanping City, the "forest ecological bank" has signed cooperation agreements with village-level operation platforms, giving full play to its capital, technology, and management advantages. Through single or combined forms such as forest proper redemption, forest land leasing, forest trusteeship, and other forms, and without changing the ownership

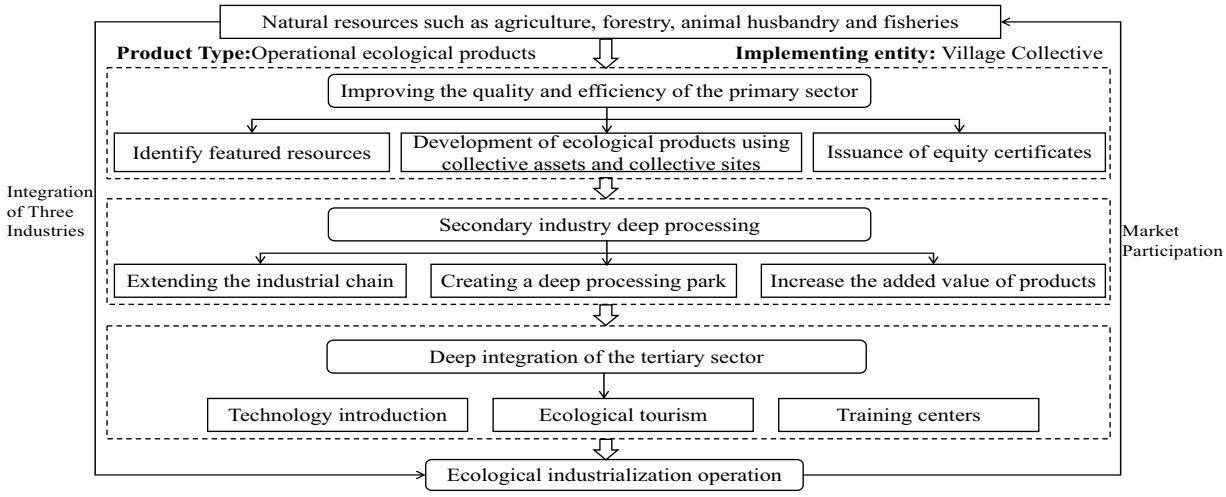

Fig. 6. Theoretical logic diagram of turning owned capital into share capital.

Fig. 7. The case of property rights trading of ecological resource indicators in Nanping City, Fujian Province, China. Shunchang Forest Ecological Operation Centre (http://fjnews.fjsen.com/2023-08/18/content_31390614.htm); (b) understory planting in state-owned forests (https://lyj.fujian.gov.cn/zxzx/lydt/sxdt/202304/t20230420_6152291.htm).

of forest land, it carries out large-scale, intensive, and specialized operation of dispersed forestry resources so as to enable householders to obtain long-term, sustainable and stable returns.

Secondly, joint-stock cooperation may be implemented to turn householders into shareholders, and realize "one share for each household." Through the flexible transfer of forest rights, improved financial services, and other initiatives, the "forest ecological bank" operation may become more standardized and orderly. The village-level forest resource operation platform takes one family or household as a unit. It applies to equity certificates for householder, stipulating that those can be pledged and inherited but cannot be transferred. By the equity certificates, householders can obtain long-term, sustainable, and stable corresponding income through the operation of the "forest ecological bank." In turn, the "bank" pays householders the guaranteed income of the year in advance according to the agreement. Then it distributes dividends according to the agreed ratio after the profits from the main felling of the forest trees are deducted from the guaranteed income already paid. Taking a rotation period of 30 years as an example, the "forest ecological bank" one-time payment of a rotation period (30 years) guaranteed income. That is, the county state-owned forest farms will discount the 10-year pre-dividend income to 13.4 dollar/hm2 as a one-time payment to the village platform, so that forest farmers can get the income in advance. When the main logging, the forest farmer deducts the guaranteed income for re-dividend according to the agreed ratio.

Finally, to turn householders into shareholders, standardized management and operation are needed to promote realizing the value of ecological products. The idea here is that the "forest ecological bank" receives forests deposited by householders in an orderly manner and carries out standardized management to ensure the quality of afforestation. On this basis, the "forest ecological bank" takes the initiative to dock with financial institutions, innovates financial products, actively seeks the participation of social capital in joint-stock cooperation and management, plans and generates projects from the resources gathered by various parties, and develops diversified industries through professional teams, such as timber management, bamboo and wood processing, the under-forest economy (Fig. 7b), forest recreation, carbon sinks, etc., which promotes the integration and development of the primary, secondary and tertiary industries and significantly enlarges the comprehensive benefits of the resources. To give an example, Jiangkou Town householders, through the "forest ecological bank" platform, have gained "forest land + funds" shares in professional cooperatives; furthermore, >26.68 hm2 of deserted forests have been integrated and a "cherry blossom seedlings + leisure tourism" industry has been developed. After several years, those leading these efforts have successfully cultivated seven varieties of cherry blossom seedlings, and at the same time, planted honeysuckle and other Chinese herbs under the cherry blossom trees to develop the under-forest economy.

This study concludes that establishing the "forest ecological bank" mechanism in Nanping City has opened up a new channel for realizing the value of ecological products. In this model, the productivity of forest land can be emancipated, forming a win-win situation for multiple subjects. Compared with the fragmented management of householders, the benefits can be increased by 30 to 50 percent through the intensive management of "forest ecological banks." In Nanping City, awareness that "everyone is a shareholder" has been significantly strengthened, and the forest area has become more secure and stable. In addition, through such large-scale management of dispersed forest land resources, it has been possible to increase forest stock, optimize the structure of forest stands, reduce soil erosion, and protect biodiversity (Fig. 8).

5. Discussion

5.1. How the "three changes" reform empowers the realization of ecological product value in the context of adaptive governance

In the context of this study, we focus on promoting ecological product value realization through reform. First, based on reviewing the achievements in realizing the value of ecological products, we constructed a theoretical logic diagram of ecological product value realization to support our study (Fig. 9). Ecological products integrate natural and social attributes [42]. Ecological resources can be transformed into material wealth [43], which can feed the ecological environment [44], meaning the two are mutually beneficial and symbiotic, with two-way conversion. The realization of ecological product value effectively expands the avenues for sustainable development by transforming ecological resources into measurable economic assets [45]. Therefore, establishing a mechanism for realizing the value of ecological products promotes green and sustainable development and the harmonious coexistence of human beings and nature.

Furthermore, we compared and analyzed the characteristics and effectiveness of different models for realizing ecological product value, from three case studies (Table 2). The realization of ecological product value is systematic and complex and requires localities to choose different models according to their conditions. Turning ecological resources into ecological assets mainly relies on government instruments to revitalize natural resources, which depend on fiscal transfers, etc., to purchase ecological products and realize their value. The mode of turning owned capital into share capital is mainly taken up in the case of creating village collective capital, which is invested in various types of business entities, ecological industrialization management, industrial chain expansion, and the promotion of deep and sophisticated processing. The mode of turning householders into shareholders is mainly

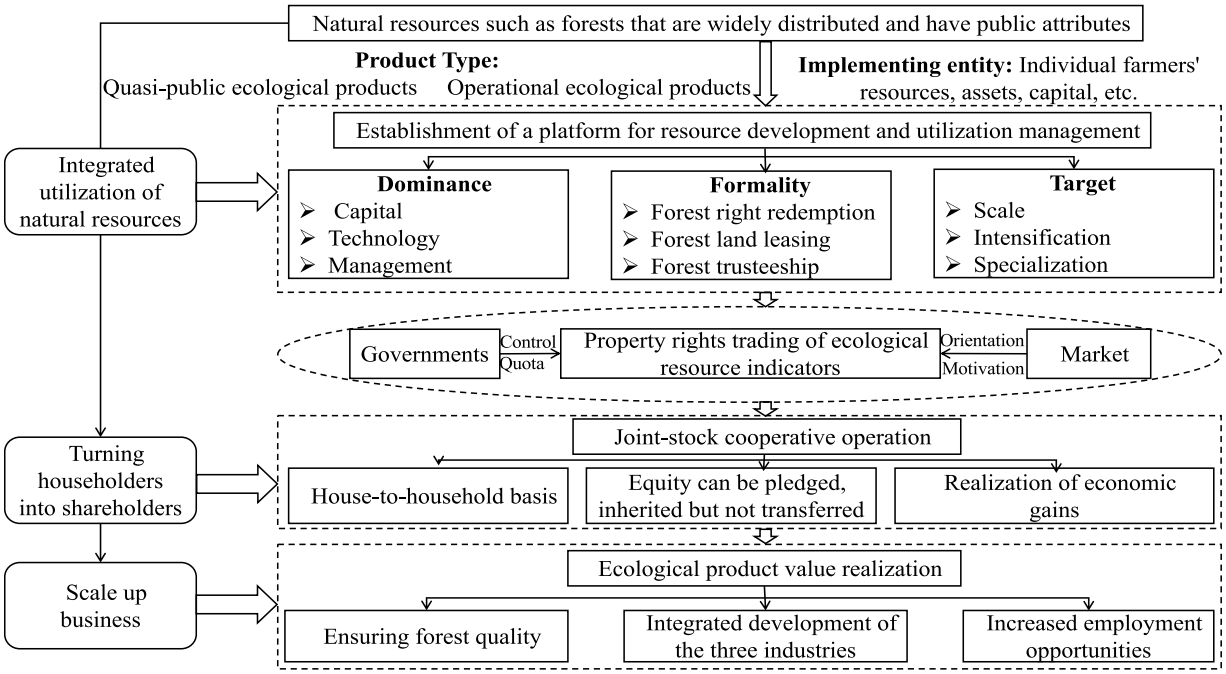

Fig. 8. Theoretical logic diagram of turning householders into shareholders.

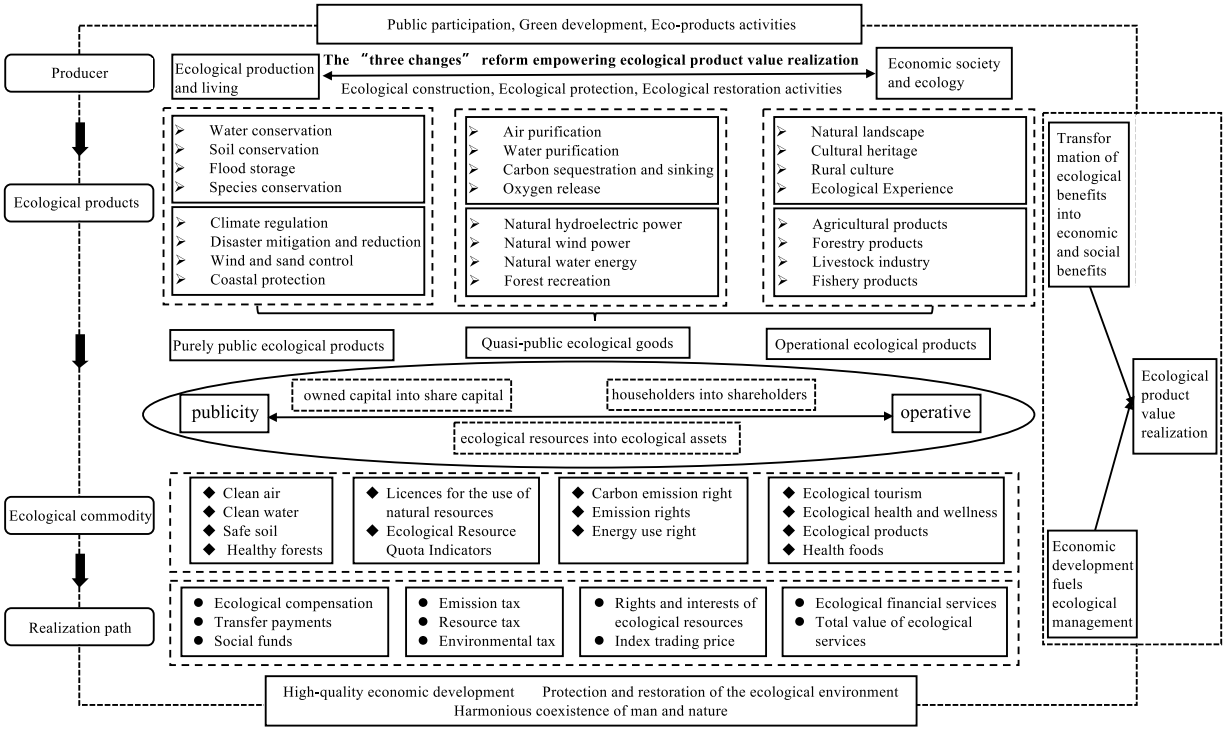

Fig. 9. Theoretical logic diagram of ecological product value realization.

embodied in government control or quota set to create demand for ecological products, as it is operated with the assistance of market means, thus encouraging and guiding householders to put their personal resources, assets, etc., into business entities and participate in the relevant property rights transaction process.

There is a strong interactive relationship between ecology, economy, and society. Regarding ecological value, the "three changes" reform model has always taken the premise of not destroying the local ecological environment as a prerequisite for development. Natural resources are the foundation of regional development. Based on the 'Three Changes' reform model, the region's natural resources are transformed into ecological products, realizing the assetization of natural resources. Improvement of the ecological environment is the basis for sustainable livelihoods. In terms of economic value, based on the property rights of ecological products, village collectives or forest farmers can quantify natural resources into shares, accelerating the aggregation of high-quality factors. Through industrial integration, value chain enhancement, and industry chain extension, the market

Table 2
Comparative analysis of three case study models of ecological product value realization.

Target level	Case 1		Case 2		Case 3	
Region	Ezhou City, Hubei Province		Mengshan County, Guangxi Zhuang Autonomous Region		Nanping City, Fujian Province	
Mode	ecological resources into ecological assets Ecological protection compensation: the essence is that the government purchases public ecological products.		owned capital into share capital Ecological industrialization operation: market development and trading of operational ecological products.		householders into shareholders Property rights trading of ecological resource indicators: create demand for ecological products through government control or quota setting to guide and incentivise stakeholder participation in market transactions.	
Product Type	Purely public ecological products		Operational ecological products		Quasi-public ecological products Operational ecological products	
Specific Practice	Establishment of the Natural Resources Accounting and Evaluation System; Establishment of a compensation mechanism for ecological protection.		Building an innovative mechanism for turning ecological resources into ecological assets, owned capital into share capital and householders into shareholders.		Pooling of scattered and fragmented forest resources into a "forest ecological bank"; Introducing and implementing FSC international forest certification.	
Effectiveness	**Before**	**After**	**Before**	**After**	**Before**	**After**
Society	There are also some abandoned factories around the inland waterways.	Small and medium-sized enterprises along the river, sand wharf or relocation or banned.	Poor brand awareness in the bee industry.	By the end of 2022, 3000 people are engaged in beekeeping; Training >500 persons.	Land low utilisation; Some householders sell their forest land outright.	The enthusiasm of the majority of householders to protect the forest has been fully mobilised.
Economy	Economic development based on industries such as mining and steelmaking.	In 2018, the total value of ecological services in Liangzihu, Echeng District and Huarong District was 8.948 billion, 7.887 billion and 6.875 billion, respectively.	Low value added products; Short industry chain and weak competitiveness.	By the end of 2022, the number of bee colonies has reached 188,000, with >200 swarms, an annual output of 2607 tons of honey, and an annual output value of >200 million for the county's beekeeping industry.	Difficulty in bringing in social capital and lack of continuity in capital investment.	Compared with the fragmented management of householders, the benefits generated by the intensive management of "forest ecological banks" can be increased by 30 to 50 percent.
Ecology	Ecological degradation; Rapidly declining wildlife.	Sewage collection and treatment rate of over 90 %; The rate of safe use of contaminated arable land has stabilized at over 91 %.	Forest cover is 82.87 percent.	Near-term harvest profit, long-term harvest forest, forest-based beekeeping and a virtuous cycle of forest-bee coordination.	The forest coverage rate reaches 78.85 percent, and the volume of forest reserves accounts for 1/3 of Fujian Province.	The forest stock in the management area has increased by 35 percent, the proportion of broad-leaved and mixed forests has increased by 20 percent.

price of ecological products will be increased, and economic income will be increased. Improving economic income level is an endogenous driving force for ecological environmental protection. At the same time, higher economic strength will, to a certain extent, improve the social status of farmers and enhance their social well-being. Regarding social value, the "three changes" reform model can provide jobs for residents by revitalizing natural resources and introducing unique industries. In addition, after training, the comprehensive strength of the farmers is increasing, which is conducive of improving social well-being. The increase in social welfare also enhances the farmers' motivation to protect the ecological environment. To sum up, China has promoted mechanisms for realizing the value of ecological products through the proposal of turning "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders," a reform method that has effectively broadened the opportunities for realizing the value of ecological products.

5.2. Similarities and differences between this study case and similar projects around the world

Many countries or regions worldwide have come to see the prospects and potential of realizing ecological product value. Accordingly, they have carried out plentiful research and practice in ecological conservation and economic development, accumulating much experience [46]. In this section, countries with different political backgrounds, such as the United States, the United Kingdom, Denmark, Brazil, and Malaysia, are selected for analysis, and it is found that coordinated socioeconomic development shares the same underlying logic.

Many countries have adopted the model of ecological protection compensation. The UK is one of the first countries to research, manage, and apply natural capital. The UK established the Scottish Natural Capital Asset Index, based on the Natural Asset Index framework designed by The Netherlands Environmental Assessment Unit, which is one of the indicators used to guide decision-making at all levels of government, organizations, and communities [47]. It provides a reference for China to build a natural resource accounting and evaluation system. The Wetland Mitigation Bank of America has clarified by law the management objective of "zero net loss" of wetland resources, introduced strict government control mechanisms, and designed institutional rules to allow for "compensatory mitigation," which has stimulated the demand for wetland compensation transactions and formed a market for transactions in which wetlands are constructed and managed by a third party in terms of their maintenance. This is highly consistent with the characteristics of China's ecological protection compensation. The difference is that China's conservation measures are based on government inputs to protect critical environmental areas and improve ecological quality. At the same time, the U.S. conservation system adopts conservation measures that do not differentiate between the classes of natural resources, such as wetlands, and inhibit the reduction in the area of ecological resources. Developing countries such as Brazil and Malaysia, on the other hand, rely mainly on fiscal transfers for ecological compensation [48]. It is consistent with the starting point of China's current environmental protection compensation policy.

Ecological industrialization operation and property rights trading of ecological resource indicators models are gradually receiving attention worldwide. Denmark has utilized innovative technologies and waste recycling measures to reduce environmental pollution in the pig industry while ensuring the production of high-quality pork. This initiative has restored the ecological environment and increased economic income, promoting the collaboration between environmental protection and economic development. It is similar to China's model of introducing specialty industries to achieve ecological industrialization operations.

The difference is that China's ecological industrialization operation model mainly relies on existing natural resources and taps into local characteristics of ecological products.

On the other hand, the Danish ecological agriculture mechanism mainly focuses on pollution prevention and control through technological innovation, thereby realizing sustainable development. The property rights trading of ecological resource indicators model mostly plays a dual role of the government and the market. For example, California in the U.S. has set a cap on the total carbon emissions allowed within a specific period. When carbon emissions exceed the prescribed limit, companies need to purchase additional carbon emission permits [49]. Under government regulation, the degree of ecological impact is quantified through carbon emission allowances. Under market guidance, rational resource development and ecosystem balance are achieved through optimized ecological product allocation.

The methods of promoting the realization of ecological product value vary in different countries worldwide. Still, the aim is to promote the transformation of ecological advantages into economic advantages and to achieve coordination between ecological protection and economic development. Developing countries are more inclined than developed countries to rely on government transfers for ecological compensation to promote realizing the value of ecological products. Developed countries are more inclined to promote the realization of the value of ecological products through market-based incentives. For China, the model of ecological protection compensation, ecological industrialization operation, and property rights trading of ecological resource indicators based on turning "ecological resources into ecological assets, owned capital into share capital, and householders into shareholders" has broadened the opportunities for realizing the value of ecological products.

5.3. *Limitations of this study and the need for future research*

Although the three cases described in this study demonstrate practical ecological and economic win-win situations regarding realizing ecological product value, there is still room for methodological improvement in how that can be judged. Firstly, in assessing the realization of ecological product value empowered by the "three changes" reform, we mainly used the economic benefits produced by ecological products as a measure for which official data were available. However, there is a lack of detailed data on the ecological benefits of ecological friendly products, including aspects such as soil fertility, water conservation, carbon sequestration, and oxygen production. Additionally, there is insufficient information regarding the social benefits, such as the health of residents, their sense of cultural identity, and their motivation for ecological protection. We could only analyze those qualitatively through our observations and interviews. Obtaining quantitative data to describe the ecological and social benefits of realizing the value of ecological products remains a challenge for future research. Secondly, the long-term effectiveness of realizing the value of ecological friendly products requires ongoing monitoring and evaluation by multiple sectors. This necessity presents a challenge in quantifying the effectiveness of ecological product value realization. Therefore, future research in various fields should turn researchers' and policymakers' attention toward the multiple aspects of realizing ecological product value. Meanwhile, researchers should conduct long-term testing and assessments to ensure that the ecological, economic, and social benefits produced by ecological products are mutually reinforcing to promote green and sustainable development. Finally, only one province each in eastern, central and western China was selected as the study area, resulting in a somewhat limited representativeness of the results. Due to differences in geographic, economic, cultural, and social development, this selection may not fully reflect national trends. At the same time, the specificity of localized provinces may affect the generalizability of the research findings. Therefore, future studies should consider expanding the sample to include more provinces in order to obtain more representative and broadly applicable results.

6. Conclusions

The traditional single development model is no longer suitable for today's development trend; we need to explore new options through continuous reform if we are to truly realize the ecological benefits and economic benefits of development [50].

First, we need to enhance the accounting system for the value of ecological products. Compiling a catalog of ecological products is a fundamental step in improving the mechanism for realizing their value [51]. Currently, the existing ecological product accounting framework aligns with the United Nations' "System of Environmental-Economic Accounting - Ecosystem Accounting" (SEEA-EA) and the "Specification for Accounting the Total Value of Ecological Products (for Trial Implementation)" issued by the National Development and Reform Commission and the National Bureau of Statistics. This framework divides ecosystems into various sub-systems, including forests, grasslands, farmland, wetlands, deserts, urban areas, oceans, and others. However, it does not account for rural ecosystems. As a major agricultural nation, China has significant potential for rural development [52], making it crucial to include rural ecosystems in the accounting of ecological product values. Rural ecosystems can also be categorized into three types: ecological products that supply materials, regulatory services, and cultural services.

Secondly, collective economic organizations serve as a key vehicle for development. Village collective economic organizations are grassroots organizations with Chinese characteristics. The realization of the value of ecological products presents a significant opportunity for the growth of the collective economy. Compared to individuals, collective economic organizations have distinct advantages in integrating village ecological resources and other aspects [53]. By identifying local resources that are unique to the area, these organizations can participate in realizing the value of ecological products through methods such as leasing and shareholding. They utilize collective assets and communal land to develop ecological products, and once they reach a certain scale, they can also promote the forest economy and expand the industrial chain. Through continuous reform and innovation, collective economic organizations have successfully explored various pathways for transforming the value of ecological products.

Third, improve the benefit distribution system. The realization of the value of ecological products is a complex systematic project that requires the joint participation of the government, enterprises, residents and other subjects. The realization of the value of ecological products involves production, circulation, sales and other links. Therefore, a scientific and reasonable benefit distribution mechanism is particularly important. Referring to the benefit distribution system of the forest ecological bank, the first year will give forest farmers dividends according to the local flow price, and the subsequent years will be dividends at a certain price. During harvesting, the revenue would be divided into two parts: 30 % and 70 %. The 30 % share received by the forest farmer would be adjusted by deducting any prepaid dividends from prior years, and the remaining profit would be disbursed to the farmer as a lump sum. The fair and reasonable distribution of benefits helps to promote the virtuous circle of "who pollutes, who compensates, who protects, who benefits".

Fourth, the construction of a market-oriented trading mechanism for ecological products should be strengthened. The realization of the value of ecological products cannot rely solely on the government; it also needs to play the role of the market in resource allocation. Therefore, it is necessary to strengthen the construction of the market-oriented trading mechanism for ecological products and reduce the cost of transforming the value of ecological products. It requires the government and the market to continuously play a role in the precise matching of supply and demand of ecological products, prices of ecological products, trading mechanisms [54], taxes and fees, compensation [55], and other aspects. Relying on the construction of a strengthened trading mechanism for ecological products through ecological industrialization,

the industry chain of ecological products is continuously extended, and the added value of products is enhanced, which in turn improves the enthusiasm of local governments and enterprises in promoting the realization of the value of ecological products.

Fifth, it is essential to improve the ecological civilization system. A sound and complete ecological civilization institutional system is an effective way to effectively curb the excessive commercialization of ecological resources. Therefore, it is necessary to establish and improve the system of property rights for natural resource assets, the system of integrated and coordinated control of territorial spatial planning and use, and the system of ecological environment monitoring and evaluation. At the same time, a scientific access mechanism should be established by quantitatively assessing the comprehensive value of ecological products. That is, a weight allocation method is adopted to evaluate the ecological value of an area, in which the ecological benefit accounts for 40 %, community participation accounts for 30 %, cultural heritage accounts for 20 %, and economic benefit accounts for 10 %. Only when the overall score reaches 80 or above can the value of ecological products be transformed and utilized. By relying on this approach, the problem of community exclusion caused by the influx of capital can be alleviated, and the realization of the value of ecological products can be promoted.

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CRediT authorship contribution statement

Jiaxu Ling: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Xiaomeng Liang:** Writing – review & editing, Resources, Investigation. **Jingran Zhang:** Writing – review & editing, Validation. **Yongji Xue:** Visualization, Validation, Supervision, Conceptualization. **Guangchao Liu:** Visualization, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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